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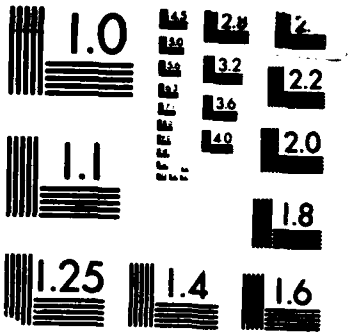

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A planar IC-compatible transferred electron device for millimeter-wave operation

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Planar IC compatible transferred electron device with a control gate; computer simulation; device fabrication; 50 Ohms stripline test circuits; transit-time oscillations at 12.9 GHz with 1% efficiency and at 19 GHz with 4% efficiency; stable small signal amplification with 0.4db gain at 38.4GHz$\pm$50MHz.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Computer simulations are presently being performed in order to optimize device parameters. ~~In particular~~, both optimum donor density and drift length will be calculated.
Device fabrication is now well under control. 70 % of the fabricated devices exhibit the precalculated low field characteristics such as DC-resistance and Schottky diode characteristics.
RF performance in the transit-time independent mode is not yet satisfactory. However, very good efficiencies have been measured in the transit-time mode:

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- Radiofrequency

20 ABSTRACT continued

At 19 GHz efficiencies between 3.5% and 4% have been measured. In this mode domain formation occurred somewhere underneath the negatively biased gate. This device ~~thus~~ is an excellent planar Gunn oscillator.

~~However,~~ the goal ~~of this work~~ is to operate this device at non-transit-time related frequencies above the transit-time frequency with comparable or higher efficiency. Up to now the tested devices did not exhibit sufficiently large negative conductance in Ka-band (26.5 - 40 GHz). Certainly, one reason for measuring low small signal gain is the low characteristic impedance of the stripline test circuit (50 Ohms). Other reasons might be some losses of the FET-like cathode contact and the steeply falling electric field distribution in the drift region due to the large donor density. Future devices therefore will be made from lower doped epitaxial layers and will be mounted in specially designed stripline circuits containing impedance transformers or resonators.

The work accomplished during the second period of the contract ending February 28, 1987 includes:

- computer simulation
- device fabrication
- design of stripline circuits with and without transformers
- mounting of 2 types of devices
- testing devices at several frequencies (12 GHz - 40 GHz)

Computer simulation

The one-dimensional computer program adapted for use on an HP 9836 CS desc top-computer has been debugged and is now working satisfactorily. Presently devices with lower doping levels (10^{15} - 10^{16} cm^{-3}) are being investigated because a low donor concentration could lead to a more uniform field distribution within the drift region and, hence, to higher DC to AC conversion efficiency. In addition, it is expected that losses within the FET - like cathode contact are lower at lower doping levels. Results are on the way.

Device Fabrication

The technological difficulties reported in the 1st interim report in November 1986 have been removed by introducing reactive ion etching. All the processing steps are now well under control and all three batches of devices fabricated up to now exhibit the precalculated low field characteristics with an average of 70% yield. 25% of the devices suffered from shorted gate-source oxide layers and 5% showed other defects such as peeled off contact layers, etc. Figure 1 shows SEM micrographs of two devices having two different drift regions (2.5 μm and 3.5 μm long).

Device Parameters

The goal of this research project is to build an oscillator which exhibits negative resistance and small reactance over a broad band of

frequencies centered around 35 GHz. In order to achieve this a large doping times drift length product should be used. However, large doping levels cause strong field gradients decreasing towards anode due to the reduced electron injection which is required for stable, Gunn domain-free operation. Therefore, donor density as well as drift length should be kept sufficiently small. Optimum values are presently calculated by means of computer simulations. The experimental devices presently under test have been made from 0.5 - 1 μm thick epitaxial layers with doping densities between 1 - $3.10^{16}cm^{-3}$ and with drift lengths varying between 2.5 and 5 μm. All devices were 400 μm wide.

Electrical Characteristics

The low field resistance of the devices tested varied between 20 (second and third batch) and 40 Ω (first batch) in very good agreement with precalculated values.

RF-data obtained with 20 Ω devices mounted at the end of a 50 Ω strip-line having a total drain-source length of 8 μm can be summerized as follows:

a) Transit-time oscillations at 19 GHz occurred at gate bias voltage V_G = 0V (18.75 GHz) and V_G = -1V (18.8 GHz) and at drain bias pulses V_D = 7V with a DC-AC conversion efficiency between 3.5 - 4 %, RF-power = 40 mw. Some samples have been operated CW, but heat sinking was not optimized.

This mode of operation is characterized by cyclic nucleation of dipole domains at a nucleation site somewhere underneath the gate according to a drift length of $L_D = 10^7 cms^{-1}/19$ GHz = 5.3 μm. No circuit tuning is needed in this mode making this oscillator - basically a planar Gunn diode - a very simple and uncritically operated planar oscillator. However, smaller dimensions would be required for operation at 35 GHz.

b) Transit-time oscillations at 12.9 GHz occurred at a gate bias voltage V_G =-0.8V and at drain bias pulses V_D = 9V with a DC-AC conversion efficiency of 1%, RF-power = 5 mw.

This mode of operation is characterized by cyclic domain formation at the ohmic source contact. The total transit length is ≈ 7.8 μm leading

to the observed transit-time frequency of 12.9 GHz. Again, no circuit tuning was required to operate this oscillator.

c) Stable amplification at Ka-band (26 - 40 GHz) frequencies

When the negative gate bias voltage is increased beyond -4V transit-time oscillations cease. No oscillations can be detected at any frequency. In this state the device should exhibit broadband negative resistance at any frequency between half the transit-time frequency and the intervalley scattering frequency ($\sim$150 GHz for GaAs). If realistic values for parallel plate capacitance and bonding wire inductance are assumed the device under test should exhibit small signal gain of several db over a few GHz. However, only a few tenth of a db have been measured at 38.4 GHz $\pm$50 MHz (U_{DS} = 5.3V; U_{GS} = -6V). Obviously, some additional loss mechanisms play a role which have not yet been identified.

Conclusions and Future Research Plan

Future work will concentrate on identifying the up to now unknown loss mechanism. One possible mechanism could be a lossy region under the overlapping gate cathode structure. Our computer simulation does not take into account any loss in this region as it uses an idealized "infinitely thin" cathode contact without any voltage drop across it. To minimize the voltage drop in this region we have designed an entirely new gated cathode structure. A set of new masks has been ordered and will be delivered in the second half of March. Also, a strip line transformer has been designed converting the 50Ω-impedance up to 120Ω which will enhance the reflection gain considerably.

Personnel

Dr. Kurt Lübke, Helmut Scheiber, Thomas Neugebauer, Christoph Schönherr, Gabriele Roitmayr and Johann Katzenmair.

Annex

The amount of unused funds remaining on the contract at the end of the period covered by the report is \$ 79,580.00 minus \$ 14,700.00 for which an invoice has been submitted in March, 1987.

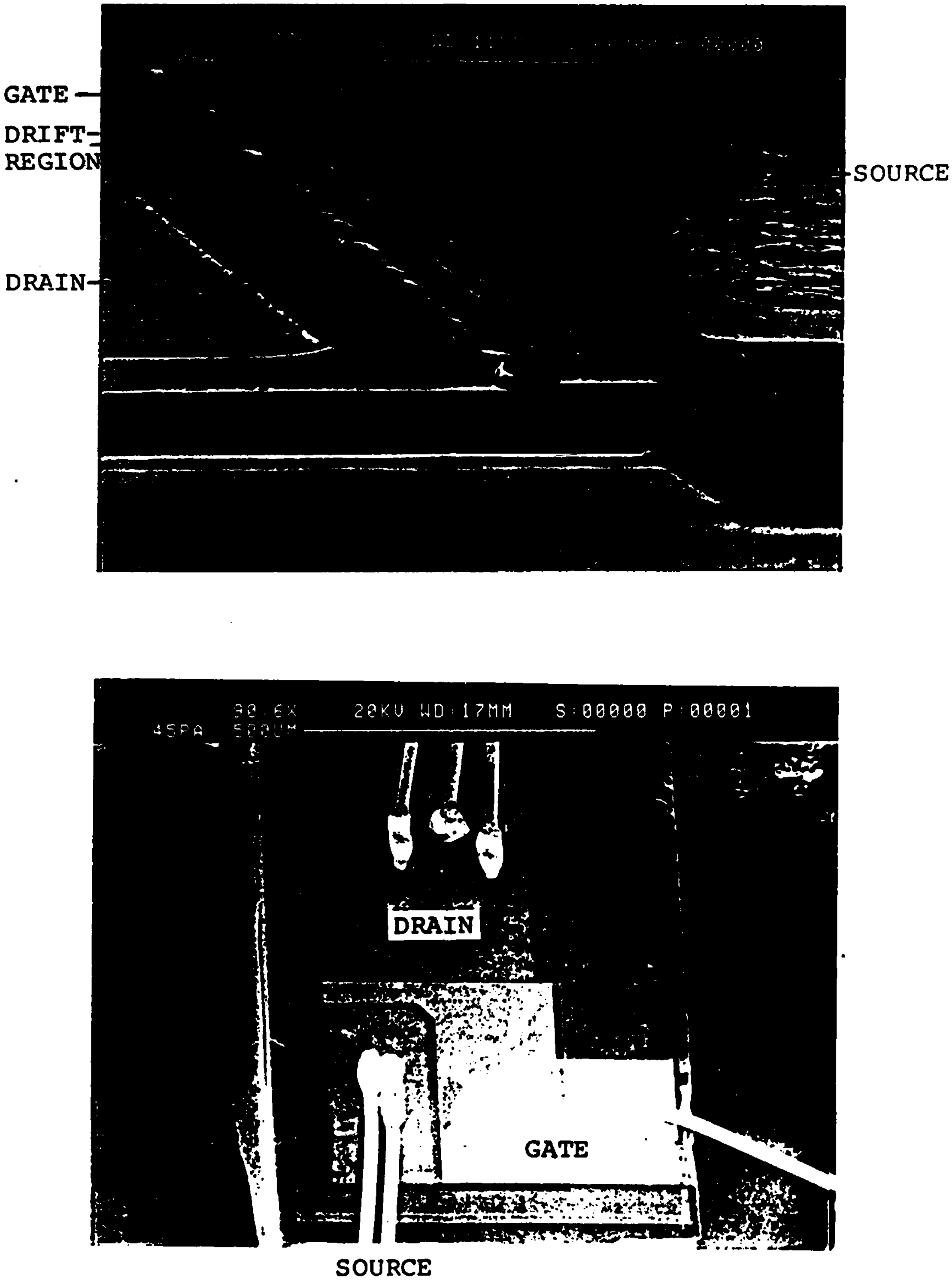
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Figure 1

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